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POST-TRIP CONTROL, TIME STANDARDS AND PREDICTIVE DIAGNOSTICS IN THE TECHNICAL SERVICE OF INTERNATIONAL ROAD TRAINS ON THE TRANSIT ROADS OF UZBEKISTAN

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Abstract. International road trains of Uzbek carriers cover about 7 thousand km per round trip on transit corridors, yet their maintenance is still planned by norms that do not define what must be checked after a transit trip and use time standards developed for other conditions. This study presents an experimental investigation carried out in 2024–2025 on MAN, DAF, VOLVO and Mercedes-Benz tractor units (mean age 12.9 years) and semi-trailers operating on the Andijan – Ivanovo route (round trip 7 230 km, four border crossings). Data were obtained from waybills, maintenance logs, on-road failure records, telematics and time studies, and processed with the 3σ rule, Weibull fitting with median ranks and the χ^2 test. The composition of post-trip control, TO-1 and TO-2 operations for the tractor and the semi-trailer was specified; a method for establishing time standards with a transit correction factor was developed; the required number of observations was shown to be 16–64 for time studies and at least 36 per component for life estimation. Using the complex coefficient of transit operating conditions $K_{tr} = 0.850$, a trip-multiple maintenance interval of 7 trips (50 610 km) was obtained for a 60 000 km base interval. A predictive diagnostics procedure is proposed in which the release of a road train for the next trip depends on the forecast residual life of components and the location of "Service area" complexes on the route; an illustrative example shows that the shape exponent of the wear curve changes the forecast residual life from 35 to 65 thousand km. A field trial at "Vodiy Bars Trans Elit" LLC increased technical availability from 0.82 to 0.89 and reduced maintenance time by 28 %, failures by 35 % and operating costs by 22 %.

Keywords: International Road Train, Transit Route, Maintenance, Post-Trip Control, Time Standards, Predictive Diagnostics, Residual Life, Weibull Distribution, Technical Availability

Introduction. International road freight is the backbone of the foreign trade and transit of Uzbekistan, a double-landlocked country. Presidential Resolution PQ-28 of 27 January 2025 sets the targets of increasing transit cargo from 13.9 to 22 million tonnes by 2030, doubling international road freight and building about 400 roadside service facilities [1]. The CAREC corridor performance monitoring reports an average truck speed without delay of only 46.1 km/h on Uzbek corridor sections [2], which means that a considerable part of each trip is spent at border crossings, in queues and in settlements.

A typical international road train of the carriers of the Fergana Valley – a tractor unit with a semi-trailer – runs 3–7 thousand km per trip through several countries, with different road categories, a mountain pass, border crossings and climatic zones. The driving and rest regime of the crew is regulated by the AETR agreement [3, 4], which, as shown earlier by the author and colleagues [5], determines both the trip duration and the places of mandatory stops. The analysis of foreign

practice of truck services on international transit highways [6] and the first experimental studies of truck operation on transit routes [7, 8] showed that the wear intensity of units, the failure flow and the required maintenance (TO) intervals in such conditions differ substantially from those of urban and local transport.

In most domestic carriers the maintenance of modern MAN, DAF, VOLVO and Mercedes-Benz tractors is organised either according to the Regulation of 1986 [9] or according to manufacturer service books that do not reflect the road and climatic conditions of Central Asia. Both approaches share two weaknesses. First, they do not define what has to be checked after each long transit trip, although it is precisely after the trip that a carrier decides whether the road train may be released for the next 7 thousand km. Second, the time standards for operations are taken from documents developed for other vehicles and conditions, so the planned downtime at the base does not correspond to the actual work content.

The **aim** of this study is to develop and test experimentally (i) the composition of post-trip control and TO-1/TO-2 operations for the tractor and the semi-trailer of an international road train, (ii) a method for establishing time standards for these operations with a transit correction factor, and (iii) a predictive diagnostics procedure in which the decision to release the road train for the next trip is based on the forecast residual life of components and on the location of service facilities along the route. The trip-multiple maintenance interval derived from the complex coefficient of transit operating conditions K_{tr} is used as the planning frame.

Materials and methods. The regularities of changes in the technical condition of vehicles and the principles of planned preventive maintenance were formulated by E.S. Kuznetsov, G.V. Kramarenko and G.M. Napolsky [10–13]; for Uzbekistan these methods were made available in the textbook and in the Uzbek edition of Kuznetsov's textbook prepared under the general editorship of Q.M. Sidiqnazarov [14, 15], while the organisation of car service is summarised in the handbook by Q.M. Sidiqnazarov and co-authors [16]. V.M. Mikhlin developed the forecasting of machine condition from the change of a diagnostic parameter [17]. Labour standardisation by work-day photography and time studies is described in [18]; for passenger cars in Uzbekistan S.S. Ortiqov proposed a method of determining time standards and a model of component life [19, 20], and with B.A. Qayumov an instruction for determining labour intensity [21]. V.A. Topalidi and U.B. Yusupov showed for specialised quarry trucks that tyre resource norms must be corrected by coefficients reflecting the actual road conditions [22, 23] and that maintenance support has to be treated as part of transport logistics [24]. Condition-based maintenance and remaining-useful-life prognostics are reviewed in [25, 26]; R. Prytz et al. predicted compressor repairs of Volvo trucks from on-board data [27], and general prognostics principles are given in ISO 13381-1 [28]. The two-parameter Weibull distribution [29] and the practical estimation of its parameters from small samples [30, 31] are used for component life.

Object of the study and route. The study was carried out in 2024–2025 at the production bases of "Vodiy Bars Trans Elit" LLC and "Bobirmirzo Hamkor Trans" LLC (Andijan), which perform international transit transportation [32]. The objects were tractor units and semi-trailers of Fergana Valley carriers operating on the Andijan – Russian Federation (Ivanovo) route (Table 1).

Table 1. Road trains studied

No	Tractor: make, model	Year	Power, hp	Semi-trailer: make, type	Year	Gross mass, t (tractor / semi-trailer)
1	MAN TGX 18.440	2011	440	Kässbohrer Mega, curtain-sider	2011	– / –
2	MAN TGX 18.440	2016	440	Schmitz Cargobull, reefer	2015	19.0 / 39.0
3	MAN TGX 18.440	2016	440	Schmitz Cargobull, reefer	2015	19.0 / 39.0
4	DAF FT XF 105.460 SSC	2012	460	Krone SD, curtain-sider	2013	19.0 / 41.0
5	DAF XF 510 FT	2016	510	Kögel SN 24, curtain-sider	2018	19.5 / 39.0
6	Mercedes-Benz 934.03 (Actros)	2006	408	Krone SDP 27, curtain	2010	18.0 / 39.0
7	VOLVO FH 4x2T	2008	440	Humbaur HSA, curtain	2007	20.0 / 39.0

The tractors were manufactured in 2006–2016; their mean age in 2025 is 12.9 years (Fig. 1). The kerb mass of road train No. 1 is 7 820 kg (tractor) and 6 660 kg (semi-trailer).

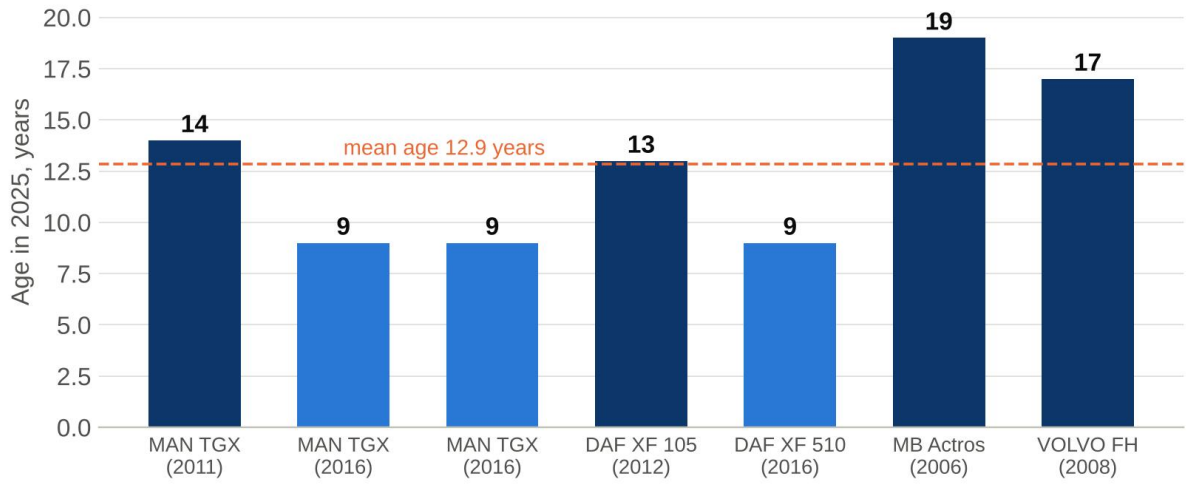


Figure 1. Age of the tractor units studied (2025)

The main trip runs Andijan – Tashkent – Shymkent – Kyzylorda – Aktobe – Orenburg – Samara – Ulyanovsk – Nizhny Novgorod – Ivanovo. The one-way distance is about 3 610 km (Andijan – Tashkent along the A373 through the Kamchik pass about 330 km, Tashkent – Samara 2 335 km [33], Samara – Ivanovo 948 km [34]); the round trip is $L_r \approx 7\,230$ km with four border crossings. Each road train makes two round trips per month; with a trip duration of about 15 days the average daily mileage is about 480 km. At 46.1 km/h [2] the driving time per trip is about 157 h, i.e. 10.5 h per day, which exceeds the AETR daily limit for one driver (9 h) [3]; the trips are therefore performed by two-driver crews.

Data sources, equipment and research program. Initial data were taken from waybills and CMR consignment notes, maintenance and repair logs and work orders, records of on-road failures and assistance calls, telematics and on-board computers (engine hours, idle time, fuel consumption, fault codes), warehouse records of spare parts and time studies in the workshop. Data collection forms record, for each failure, the vehicle, date, odometer reading, system and unit, place (base or road, type of route segment), method of elimination, time and cost. Manufacturer diagnostic tools (MAN-cats III, DAF DAVIE, Volvo Tech Tool, Mercedes-Benz XENTRY), a roller brake tester for trucks, tread depth and lining thickness gauges, a digital stopwatch and video recording, telematics portals and MS Excel were used. The research programme included six stages (Fig. 2).

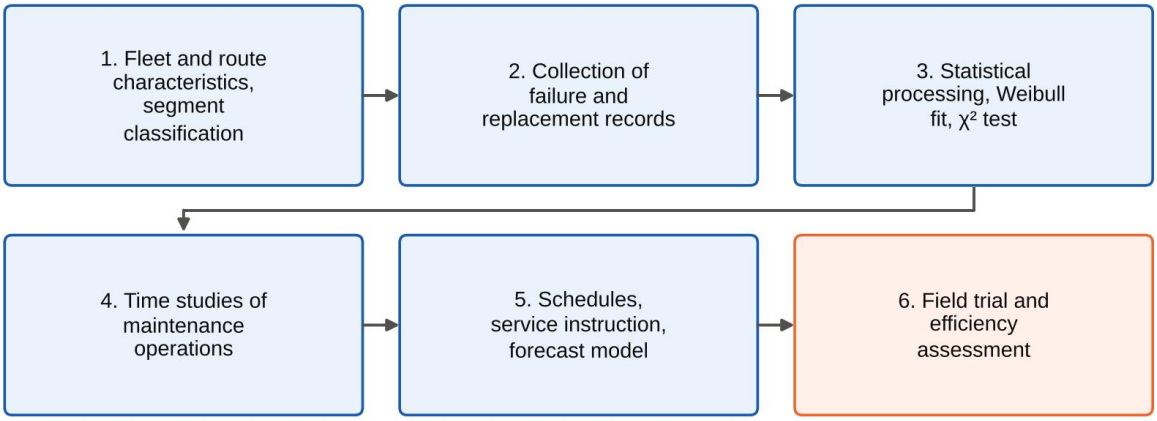


Figure 2. Programme of the experimental research

Statistical processing. The required number of observations for a given accuracy is [11, 18]:

$$n = t_\gamma^2 \cdot v^2 / \varepsilon^2 \qquad (1)$$

where t_γ is the Student coefficient ($t_\gamma \approx 2.0$ for $\gamma = 0.95$), v is the coefficient of variation and ε is the admissible relative error. Gross errors were rejected by the 3σ rule; mean, standard deviation and coefficient of variation were calculated. Weibull parameters were estimated by maximum likelihood or by regression in linearised coordinates with median ranks [30, 31]:

$$\ln[-\ln(1 - F(L))] = b \cdot \ln L - b \cdot \ln a, \quad \hat{F}(L_{(i)}) = (i - 0.3)/(n + 0.4) \qquad (2)$$

and the fit was checked by Pearson's χ^2 or Kolmogorov's criterion at the 0.05 significance level. The failure flow parameter is $\omega = 1000 \cdot n_f/\Sigma L_i$, where n_f is the number of failures and ΣL_i the total mileage of the observed vehicles.

2.5. Time standards with a transit correction factor

Operation times were determined by work-day photography and time studies [18–20]. The stability of each time series was checked by $K_s = t_{max}/t_{min}$ ($K_s \le 2.0$ for manual and $K_s \le 1.5$ for mechanised operations). The time standard of an operation is

$$t_{st} = (t_m + t_a) \cdot (1 + (\alpha_{pr} + \alpha_{ws} + \alpha_{rest}) / 100) \qquad (3)$$

where t_m, t_a are the main and auxiliary times and α_{pr}, α_{ws}, α_{rest} are the allowances for preparatory-final work, workplace servicing and rest, % of operating time. After a transit trip several operations take longer (heavier contamination, inspection of brakes and cooling after the mountain section, fastening after a long run); this is reflected by the transit correction factor

$$t_{st}^{tr} = t_{st} \cdot K_t^{tr}, \quad K_t^{tr} = \bar{t}_{tr} / \bar{t}_{loc} \qquad (4)$$

where $\bar{t}_{tr}$ and $\bar{t}_{loc}$ are the mean durations of the operation on vehicles returning from transit and local trips. Labour intensity is transferred to other makes through the make coefficient K_k relative to the base model [19].

2.6. Predictive diagnostics

The change of a diagnostic parameter with mileage is described by a power function [17]: $y(L) = y_0 + v_y \cdot L^{\alpha}$, where y_0 is the initial value, v_y the rate of change and α the shape exponent (1.0–1.6 for wear processes). From the value y_c measured at mileage L_c, $v_y = (y_c - y_0)/L_c^{\alpha}$ and the residual life to the limit value y_{lim} is

$$L_{res} = [(y_{lim} - y_0) / v_y]^{1/\alpha} - L_c \qquad (5)$$

The dispatch rule takes the transit specifics into account: if $L_{res} \geq L_r + \ell_s$ (ℓ_s – safety margin) the road train is released for the trip; if $L_{SA} \leq L_{res} < L_r + \ell_s$ (L_{SA} – distance to the nearest "Service area" on the route) the element is replaced at that complex and the spare part is ordered in advance; if $L_{res} < L_{SA}$ the element is replaced at the base before the trip.

Results. Of the 7 230 km round trip, 87.3 % is covered on category I trunk roads, 2.8 % on the Kamchik mountain section (category IV) and 10.0 % in settlements (category III). The weighted coefficients are $K_1^{tr} = 0.972$ and $K_3^{tr} = 0.903$; with 8 h of engine idling per trip and an equivalence factor of 30 km/h the idle-time coefficient is $K_x = 0.968$ and the complex coefficient $K_{tr} = 0.850$. For a base interval of 60 000 km this gives 51 000 km, rounded down to a multiple of the trip: 7 trips, or 50 610 km (Table 2). The semi-trailer is serviced together with the tractor: for a semi-trailer base interval of 100 000 km the transit interval is 85 000 km, and the multiplicity k = [85 000/50 610] = 1.

Table 2. Trip-multiple maintenance intervals for the Andijan – Ivanovo route (K_{tr} = 0.850; L_r = 7 230 km)

Base interval L^n, km	Transit interval L^{tr}, km	Trips n_r	Trip-multiple interval L^q, km	Interval at 21.6 trips/year, months
40 000	34 000	4	28 920	2.2
60 000	51 000	7	50 610	3.9
80 000	68 000	9	65 070	5.0
100 000	85 000	11	79 530	6.1
120 000	102 000	14	101 220	7.8

Composition of post-trip control and maintenance operations. Taking into account the long distance, the mountain section, idling in queues and TIR seal requirements, the operations of post-trip control (PTC), TO-1 and TO-2 were specified for the tractor (Table 3) and the semi-trailer (Table 4).

Table 3. Main operations on the tractor unit after a transit trip

Operation	PTC	TO-1	TO-2	Method, equipment
External inspection, cab and frame	+	+	+	visual
Reading of fault codes of electronic systems	+	+	+	MAN-cats, DAVIE, Tech Tool, XENTRY
Brake lining / disc thickness	+	+	+	gauge, EBS data
Brake forces and braking efficiency	–	+	+	roller brake tester
Air system tightness, air dryer condition	+	+	+	manometer, on-board computer
Steering and joint play	–	+	+	play meter
Fifth wheel check and lubrication	+	+	+	gauge
Tyre condition, tread depth and pressure	+	+	+	tread gauge, manometer
Oil, coolant and AdBlue levels	+	+	+	visual, on-board computer
Engine oil and filter replacement	–	–	+	service book
Batteries	–	+	+	load tester
Fastening (wheels, suspension, frame)	–	+	+	torque wrench
Brakes and cooling after the mountain section	+	–	–	visual, thermometer

Table 4. Main operations on the semi-trailer after a transit trip

Operation	PTC	TO-1	TO-2	Method, equipment
External inspection, body / curtain and frame	+	+	+	visual
Brake mechanisms and EBS	+	+	+	diagnostics, measurement
King pin and landing gear	+	+	+	gauge
Wheel hub bearings	–	+	+	play measurement
Suspension (springs, air bags)	–	+	+	visual
Tyre condition and pressure	+	+	+	tread gauge, manometer
Lights and electrical connections	+	+	+	visual, tester

Operation	PTC	TO-1	TO-2	Method, equipment
TIR customs seal fittings	+	+	+	visual
Refrigeration unit (reefers)	+	+	+	unit control panel

Brakes, tyres and the coupling device are checked after every trip, while labour-intensive operations are moved to TO-1 and TO-2 performed between trips. This reduces downtime at the base without reducing the scope of work. Time standards are established at the enterprise from the time-study sheet using (3)–(4).

Number of observations.

Formula (1) gives the number of observations shown in Table 5 and Fig. 3. For time studies, where v is typically 0.1–0.2, 16–64 observations are sufficient at ε = 0.05; for component life with v = 0.3 and ε = 0.10 at least 36 observations per component are required. Since one carrier accumulates such samples only over several years, the estimation of life parameters is included in the service instruction as a continuous process carried out as the enterprise database grows.

Table 5. Required number of observations n by formula (1), γ = 0.95

Coefficient of variation v	ε = 0.05	ε = 0.10	ε = 0.15
0.1	16	4	2
0.2	64	16	7
0.3	144	36	16
0.4	256	64	28
0.5	400	100	44

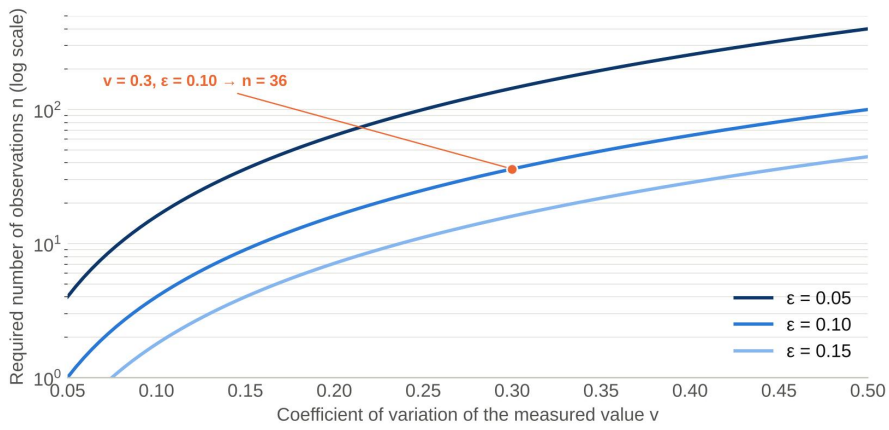


Figure 3. Required number of observations versus coefficient of variation

By the coefficient of variation, components are divided into three groups [11]: for $v < 0.33$ scheduled preventive replacement is effective; for $0.33 \le v \le 0.5$ replacement is planned together with diagnostic results; for $v > 0.5$ replacement is carried out only by actual condition.

Predictive diagnostics and dispatch decision. The diagnostic parameters monitored in predictive diagnostics are listed in Table 6; limit values are set by manufacturer documentation and mandatory requirements for vehicle technical condition [11].

Table 6. Diagnostic parameters for predictive diagnostics

System, element	Diagnostic parameter	Data source
Brake mechanisms	lining thickness, mm; wear sensor signal	measurement, EBS / telematics
Air system	compressor duty cycle; pressure drop rate	on-board computer, telematics [27]
Engine	oil pressure, coolant temperature, fault codes, idle hours	on-board computer, telematics
Battery	voltage drop at start, V	on-board computer, measurement
Tyres	tread depth, mm; pressure, kPa	measurement, pressure monitoring
Clutch	disc wear indicator, %	gearbox control unit
Fifth wheel	lock play, mm	measurement

The procedure is illustrated by a numerical example with assumed values (Fig. 4): brake lining wear $y_{lim} = 15$ mm, $y_0 = 0$, measured wear $y_c = 7.2$ mm at $L_c = 60$ thousand km. For $\alpha = 1.2$, $v_y = 7.2/60^{1.2} = 0.0529$ and, by (5), $L_{res} = 50.6$ thousand km, i.e. about seven round trips. Since L_{res} is far greater than $L_r + \ell_s$, the road train is released, and the linings are replaced at the next trip-multiple TO (after 7 trips), so the replacement does not cause additional downtime. However, the result is sensitive to the shape exponent: with the same measurement $L_{res} = 65.0$, 41.4 and 34.9 thousand km for $\alpha = 1.0$, 1.4 and 1.6. For $\alpha = 1.4$–1.6 the lining reaches the limit after about five trips, before the scheduled TO, and must be replaced at an earlier base visit. Therefore α should be estimated for each component from several measurements (telematics provides them continuously) by least squares after linearisation, rather than taken as a generic value.

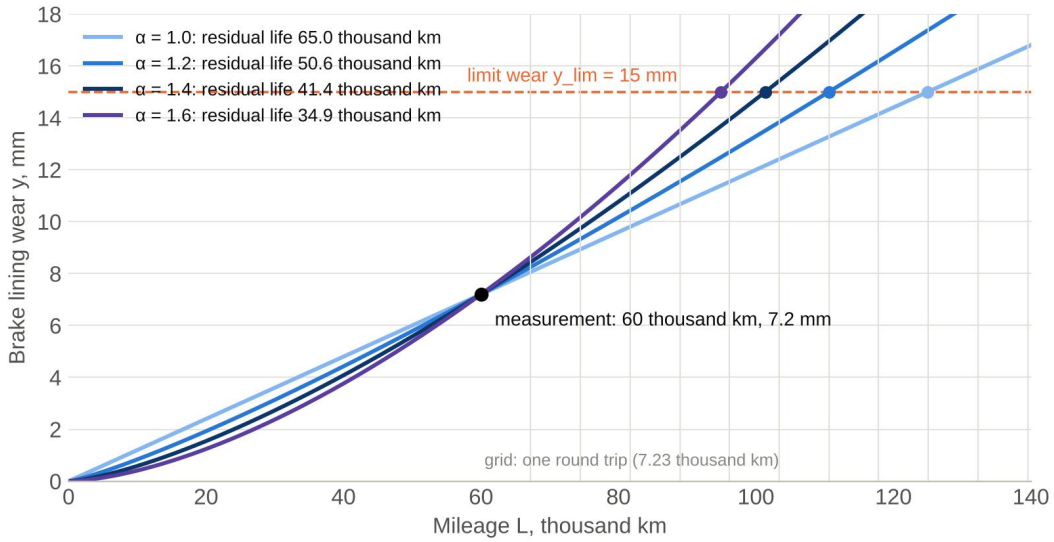


Figure 4. Forecast of brake lining wear and residual life for different shape exponents (illustrative values)

The improved algorithm of technical service at the base is shown in Fig. 5. In addition to scheduled TO, after each trip it includes the residual-life forecast and the dispatch decision, which takes into account the position of "Service area" complexes on the route.

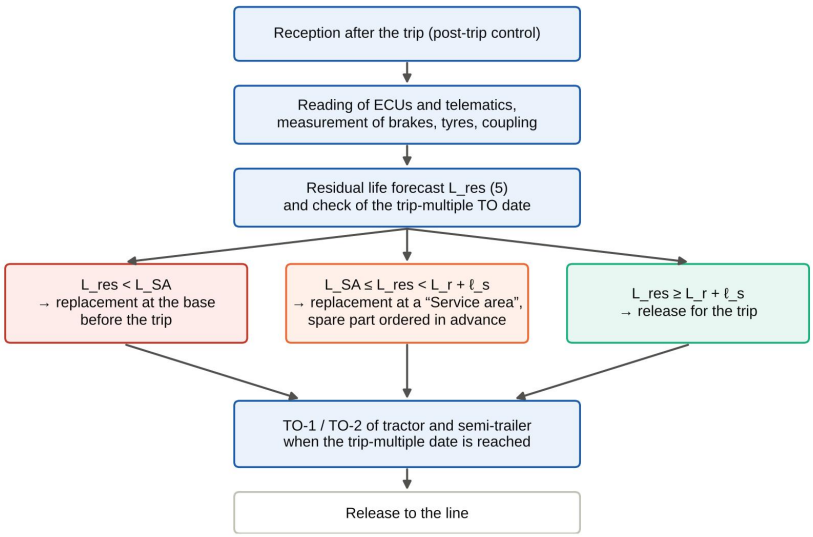


Figure 5. Improved algorithm of technical service of an international road train at the base

Field trial. The technical service instruction based on these results covers general provisions and the three-level service structure, pre-trip and post-trip control, the procedure for determining the trip-multiple TO interval, the composition of operations and their standardisation, actions in case of an on-road failure, monitoring and forecasting of diagnostic parameters, spare-parts planning and reporting forms. In 2024–2025 it was tested on a road train of "Vodiy Bars Trans Elit" LLC (MAN TGX 18.440, 2011, registration number 60 615 HBA, with a Kässbohrer Mega

semi-trailer, 2011) and implemented at the enterprise. The results are confirmed by the certificate of the Road Research Institute [32] (Table 7, Fig. 6).

Table 7. Results of the field trial of the improved technical service system [32]

Indicator	Existing system	Improved system	Change
Technical availability coefficient α_t	0.82	0.89	+0.07 (+8.5 %)
Maintenance time	100 %	72 %	−28 %
Number of failures	100 %	65 %	−35 %
Operating costs	100 %	78 %	−22 %
Annual economic effect per road train, million UZS	–	8.4	–

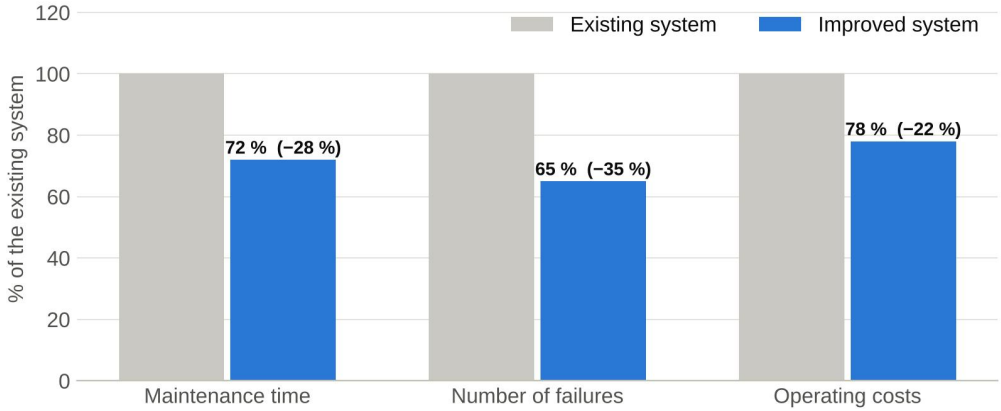


Figure 6. Change of indicators after implementation of the improved technical service system

Analysis of research results. The reduction in failures by 35 % is explained mainly by post-trip control of brakes, tyres and the coupling device and by predictive diagnostics, which prevent failures on the road, the most expensive type of failure for a transit carrier. The reduction in maintenance time by 28 % results from performing TO between trips at the base, synchronising the tractor and the semi-trailer and adapting the list of operations to transit conditions. The increase of technical availability from 0.82 to 0.89 means that, at an unchanged daily mileage, the annual mileage of a road train increases by 8.5 %.

The numerical example in Section 3.4 shows the practical value of linking the forecast to the trip structure: the decision is made not in kilometres but in trips, and the forecast either confirms that the replacement can wait for the scheduled TO or moves it to an earlier base visit or to a “Service area” on the route. This is consistent with the conclusion of V.A. Topalidi and co-authors that resource standards must be corrected for the actual operating conditions [22–24] and with the idea of condition-based maintenance [25, 26]. In contrast to approaches based on extensive telematics

data [27], the proposed procedure works with one or a few measurements and can be applied in fleets where telematics is installed only on part of the vehicles.

The study has limitations. The lengths of mountain and settlement segments were estimated from the map; the idle-time equivalence factor was assumed and should be refined by used-oil analysis; the numerical example in Section 3.4 uses assumed values and serves to illustrate the method; the trial results refer to one road train and should be confirmed on a larger fleet. These questions are addressed by the continuous collection of data provided for in the service instruction and by the author's software for freight transport calculations developed with colleagues [35, 36].

Conclusion.

1. The composition of post-trip control, TO-1 and TO-2 operations for the tractor and the semi-trailer of an international road train was specified for transit conditions: brakes, tyres and coupling devices are checked after every trip, labour-intensive work is performed at trip-multiple TO between trips.

2. A method for establishing time standards with a transit correction factor K_t^{tr} and for transferring labour intensity between makes was developed; the required number of observations is 16–64 for time studies and at least 36 per component for life parameters.

3. For the Andijan – Ivanovo route (L_r = 7 230 km) K_{tr} = 0.850, and for a base interval of 60 000 km TO is performed every 7 trips (50 610 km), simultaneously for the tractor and the semi-trailer.

4. A predictive diagnostics procedure with a dispatch rule based on residual life and the location of service complexes was proposed; the illustrative example shows that the shape exponent α must be estimated for each component, since it changes the forecast residual life from 35 to 65 thousand km.

5. The field trial at "Vodiy Bars Trans Elit" LLC increased technical availability from 0.82 to 0.89 and reduced maintenance time by 28 %, failures by 35 % and operating costs by 22 %, with an annual economic effect of 8.4 million UZS per road train.

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